MONITORING PHYTOPLANKTON IN ONTARIO'S WATER SUPPLIES

Ministry of the Environment
Ontario

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IN

ONTARIO'S WATER SUPPLIES*

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History of Programme-

The significance of algae and their impact on providing potable water supplies to the people of Ontario has been recognized as a major concern to the Ontario Water Resources Commission since its formation back in 1957. Early inputs of information on algae were primarily recommendations by the Commissions' Biologist for microstrainer installations and/or answers to queries in regards to filter clogging algae or taste and odour producing algae. Whereas today the eight member staff of the Plankton Taxonomy Unit of the Ministry of the Environments' Limnology and Toxicity Section are involved in the analyses and interpretation of plankton data and its relationship to water quality whether it is for water supply, recreation or multi-purpose uses.

In 1961, the Biology Branch, as it was then known, saw the need to provide routine monitoring of water supplies in Ontario but recognized that staff limitations would not permit adequate handling of the sampling load generated. This same year Carl F. Schenk joined our staff as an aquatic plant biologist whose responsibilities included the establishment of an algae identification and enumeration programme for the O.W.R.C. After attending the "Plankton Identification and Control" course at the Robert A. Taft Centre in Cincinnati, Ohio, Carl outlined a condensed version of this course geared to our specific needs to train water treatment plant operators to identify and count algae.

The first OWRC sponsored "Algae Identification and Enumeration" course was held in April, 1963 and the second course was held in the fall

of the same year. Those persons attending the first course were photographed for posterity and will be remembered in the "Algae Hall of Fame". Persons identified in Figure 1 are: Ted Colvin, Oshawa; Ken Allen, Kingston; Anne-Marie Kuppe, Hamilton; Jim Scriven, Belleville; Jim Harrison, Peterborough; Earl Myers, Cornwall; Alf Shingler, Cedar Springs; Len Pridie, Whitby; Vance Langford, St. Thomas; Ted Grozelle, Cobourg; Don Burden, Sudbury and John Neil, Carl Schenk, Glen Owen and myself from the OWRC. Subsequently 5 more courses were held between 1964 and 1970 accommodating 67 persons representing 33 municipal or ministry operated plants.

By 1965 Waterworks personnel at several plants, notably Goderich, Union, Dunnville, Peterborough, Belleville and Cornwall, were submitting results of phytoplankton analyses to the Biology Branch. At the same time we received additional staff to handle the influx of samples generated by the increased activities of our own field personnel collecting samples for water quality assessments, some of which included potential water supply intakes or alterations to existing ones, such as Espanola, Cobourg, Kingston, Collingwood, Midland and Orillia.

In 1965 the International Joint Commission shifted its interest to the Lower Great Lakes and embarked on a lakewide sampling programme. Sampling frequency was on a monthly basis at widely separated stations throughout the lake. This was not amenable to good interpretation for phytoplankton as year round data could not be collected due to inclement winter weather. In addition, if one cruise was missed it would mean the possibility of not returning to the site for six to eight weeks from the previous collection date. During this time important algal population pulses could be missed. The Biology Branch was successful in persuading

the I.J.C. coordinators to direct funds for phytoplankton monitoring toward sampling at water supply intakes where more frequent (regular weekly) collections could be made on a year round basis. The information could be used immediately by the waterworks personnel for plant operation purposes and in return the operational data could be used to assist in interpretation of the phytoplankton data. This was the basis for the initiation of a "Provincial Algae Monitoring Programme" at water works. Fortunately many of the water treatment plants along the Lower Great Lakes were operated by the O.W.R.C. From 1965 to 1970 samples for phytoplankton analyses were being received weekly from 15 Great Lakes Water Works on a year round basis. In 1970 this was cut back to eight as more Ministry-operated plants were having personnel trained to carry out phytoplankton analyses at the water treatment plant. Included in this group were Lampton, Amherstburg, Blenheim, Elgin area, South Peel and the Lake Huron Water Supply. Table 1 is a summary of locations where personnel have attended the "Algae Identification and Enumeration" Course and those still actively involved in the "Provincial Algae Monitoring Programme".

Since its inception in 1965 the "Provincial Algae Monitoring Programme" has generated approximately 750 samples per year for analyses by our laboratory and another 250 sample results per year from participating water works personnel. However, as we were only capable of analysing approximately 300 samples per year from water works programmes, we fell behind by about 3000 samples between 1967 and 1972. Consequently the cut-back in sample submissions in 1970 as mentioned earlier was necessary.

We have had no formal algae courses since 1970. Waterworks personnel are brought in individually as required. The emphasis within our own section has shifted to more taxonomic analyses with regional staff providing qualitative interpretation of algal related problems.

Table 1. Summary of municipalities which have sent personnel to Ministry of Environment "Algae Identification and Enumeration" Courses and Current Participants in the "Provincial Algae Monitoring Programme"

Municipality	No. of attendees	Current Active participants in Algae Monitoring Programme
Oshawa	(2)	
Kingston	(4)	x
Hamilton	(2)	x
Belleville	(3)	x
Peterborough	(3)	x
Cornwall	(3)	x
Cedar Springs	(1)	
Whitby	(1)	
St. Thomas	(1)	
Cobourg	(1)	
Sudbury	(5)	x
Toronto	(4)	x
Lindsay	(3)	x
Smith Falls	(1)	
Windsor	(1)	
Port Arthur	(1)	
Dunnville	(1)	x
Goderich	(1)	x
London	(1)	
Sarnia	(2) Lampton	x
Ottawa	(2)	
Union	(4)	x
Chatham	(1)	
St. Catharines	(1)	
Wheatley	(2)	
Toronto Twp.	(4) South Peel	x
Bertie Twp.	(1)	
Niagara Falls	(2)	
Grand Bend	(3) L. Huron Supply	x
Elgin	(2)	x
Arnprior	(1)	
Thunder Bay	(1)	
Harrow	(1)	
		Brockville
		Sault Ste Marie

Data Applications

Within two years of the initiation of the "Provincial Algae Monitoring Program" enough data had been accumulated to make a first effort at interpretation of algal densities in the Canadian Great Lakes. M.F.P. Michalski (1968) authored a paper entitled "Phytoplankton Levels in Canadian Near-Shore Waters of the Lower Great Lakes" and presented it to the 11th Conference on Great Lakes Research. Figure 2 shows the locations of waterworks intakes included in this paper. Figures 3 and 4 shows the data summary for algal biomass expressed as areal standard units per ml for the locations in the study. This was the first comprehensive picture of the current algal situation in Lakes Erie and Ontario at that time and covered the period March 1966 to November 1967. Subsequently this information was extended to the end of March 1968 for a complete two year picture which was summarized in a similar fashion and presented to the International Joint Commission as a report (Anon. 1969) entitled "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River". Concurrently, individual reports were prepared for the managers of each participating water supply.

Briefly this information indicated the comparative algal density at each of the sampling locations. Highest values were recorded at Union in the western basin of Lake Erie and the lowest were recorded at Bertie Township in the eastern basin of Lake Erie. Values for Lake Ontario were similar to those found in the central basin of Lake Erie. Both lakes showed a decrease in algal populations from west to east and with the exception of Union all locations showed seasonal bimodal population fluctuations.

Aliquots of the samples collected during these studies were used to make diatom slides for speciation purposes. A taxonomic listing of the

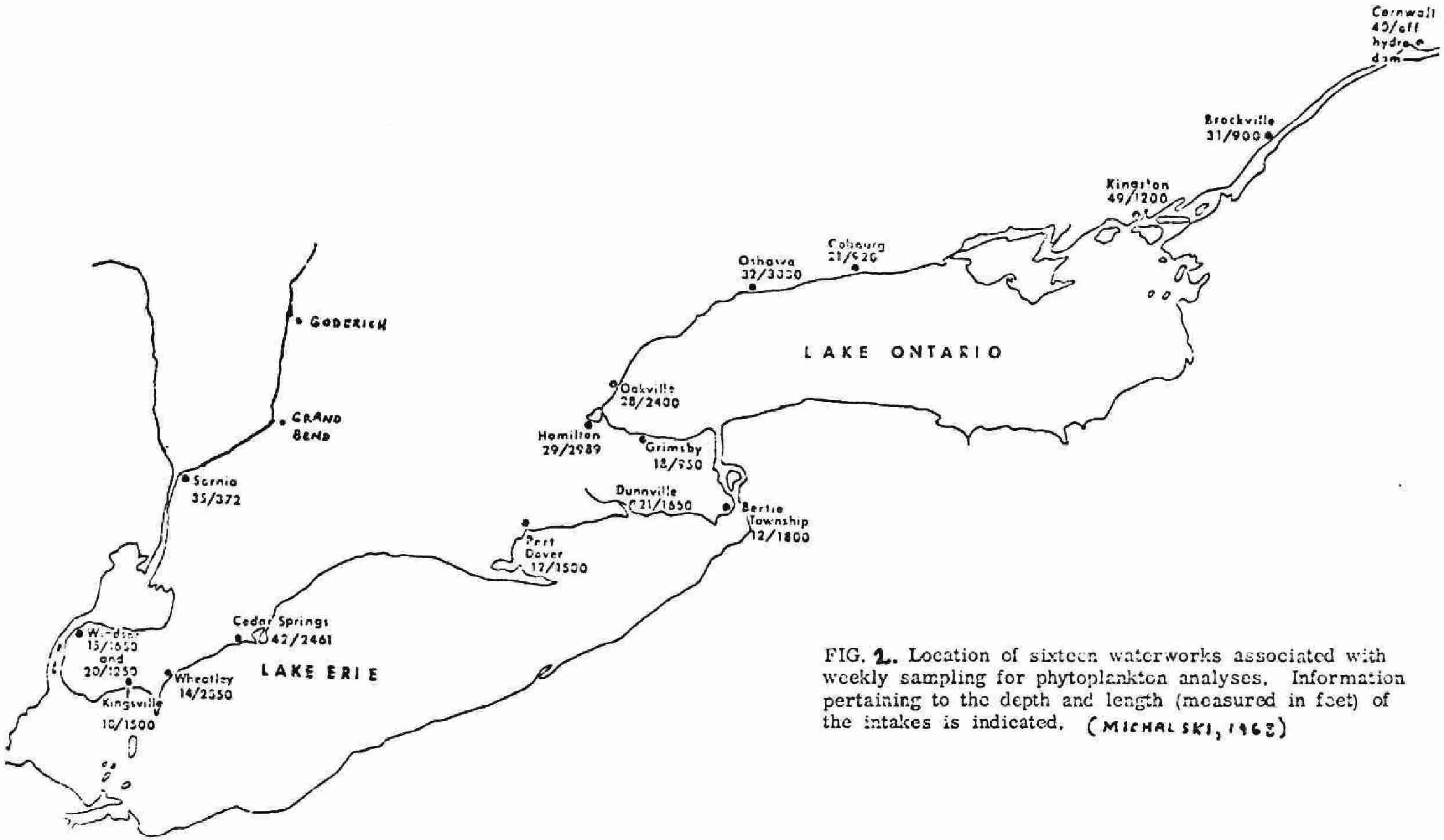

FIG. 1. Location of sixteen waterworks associated with weekly sampling for phytoplankton analyses. Information pertaining to the depth and length (measured in feet) of the intakes is indicated. (MICHALSKI, 1963)

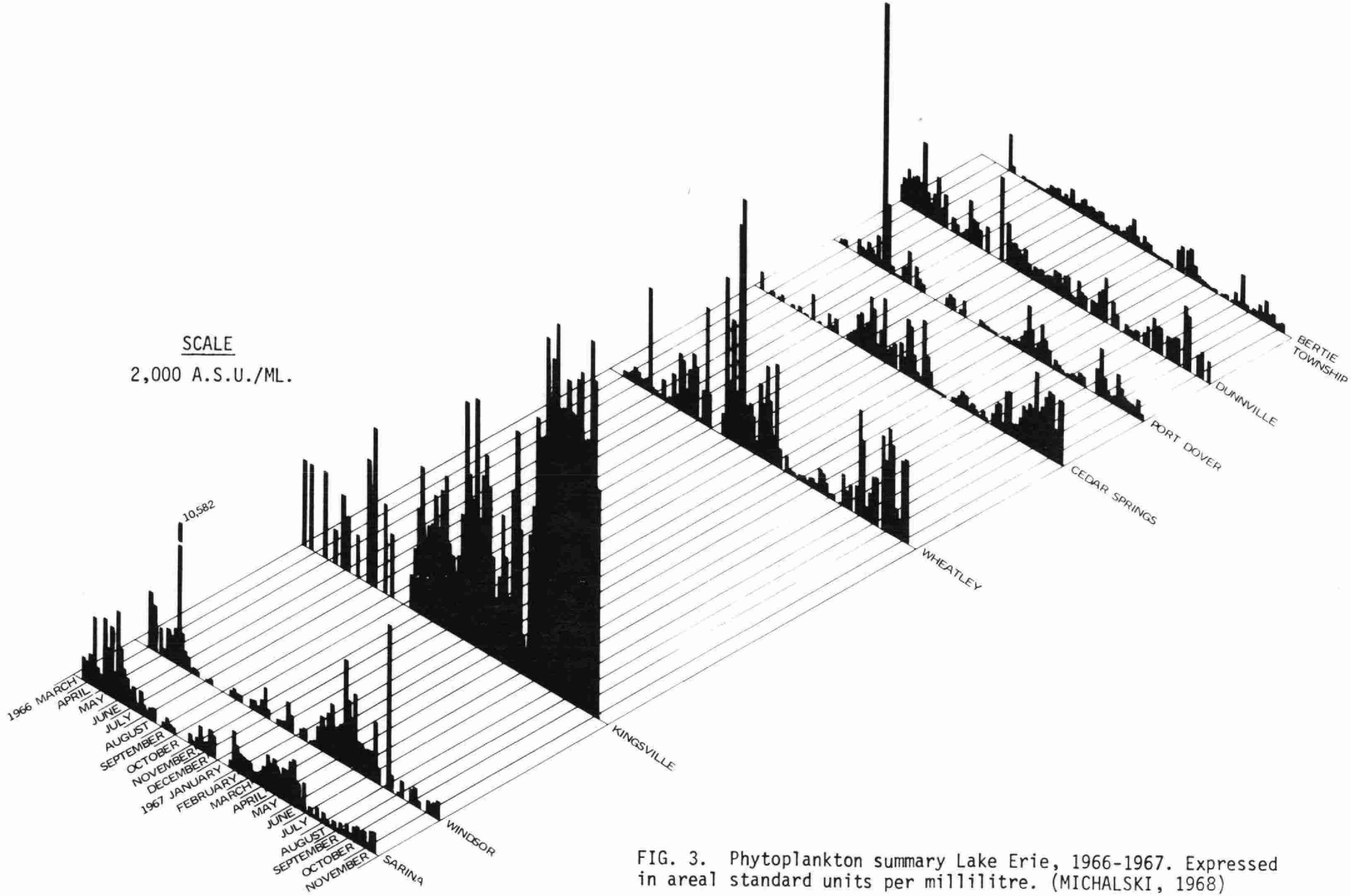

FIG. 3. Phytoplankton summary Lake Erie, 1966-1967. Expressed in areal standard units per millilitre. (MICHALSKI, 1968)

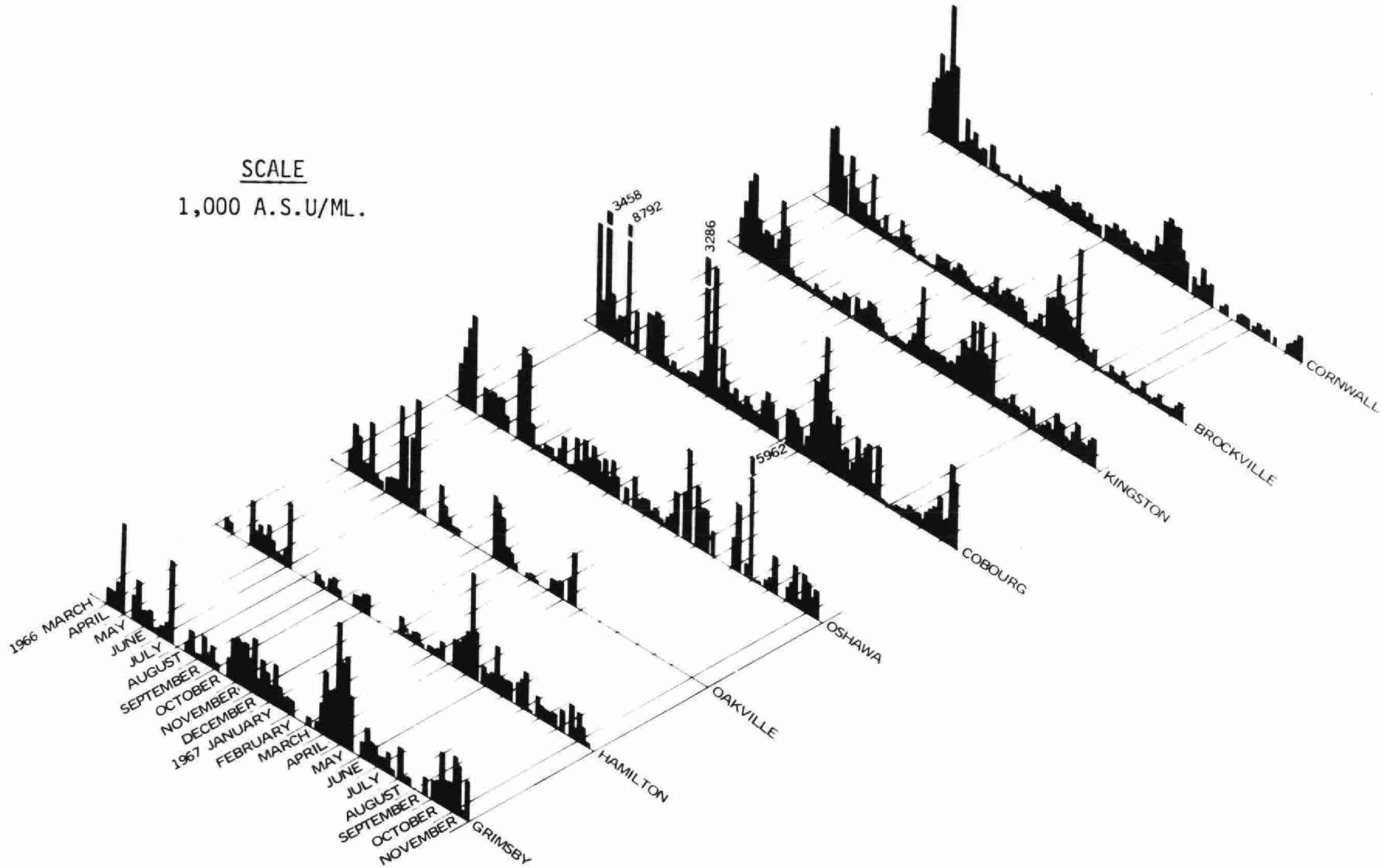

FIG. 4. Phytoplankton summary Lake Ontario, 1966-1967. Expressed in areal standard units per millilitre. (MICHALSKI, 1968)

species of algae found in these samples along with an extensive literature search was the basis for a paper by Michalski, (1969), entitled "Planktonic and Periphytic Algae of the Great Lakes" printed in "The Great Lakes as an Environment". Over 900 taxa were identified with an indication of their relative abundance throughout the Great Lakes. This listing has been updated and now provides information on well over 1000 taxa.

"Biological and Limnological Aspects of Water Supply" by Michalski and Hopkins (1971) was the title of a paper presented at the Sixth Waterworks Seminar held in November, 1971. As the title suggests, it provided an explanation of some of the chemical, physical and biological relationships within a lake system and their effects on water supply. Figure 5 is a graphical representation of the role played by available sunlight and nutrient inputs on the seasonal algal pulses. Seasonal changes in algal densities can effectively change pH, alkalinity, dissolved oxygen, and the organic content of raw water which in turn may affect proper floc formation, chlorine dosage and filter runs in the water treatment plant. In more extreme cases filter clogging and taste and odour producing algae may affect plant operation.

Cladophora is a notorious nuisance alga which frequently curtails raw water flow by plugging intake screens at the low lift well. In November, 1962 the diatom Melosira was responsible for short filter runs at nearly all the water treatment plants along the north shore of Lake Ontario with the R.C. Harris plant being severely affected. The filter beds had to be taken out of service and the blanket of algae was rolled back like large sheets of cardboard.

Places like Union and Belleville routinely turn on their microstrainers

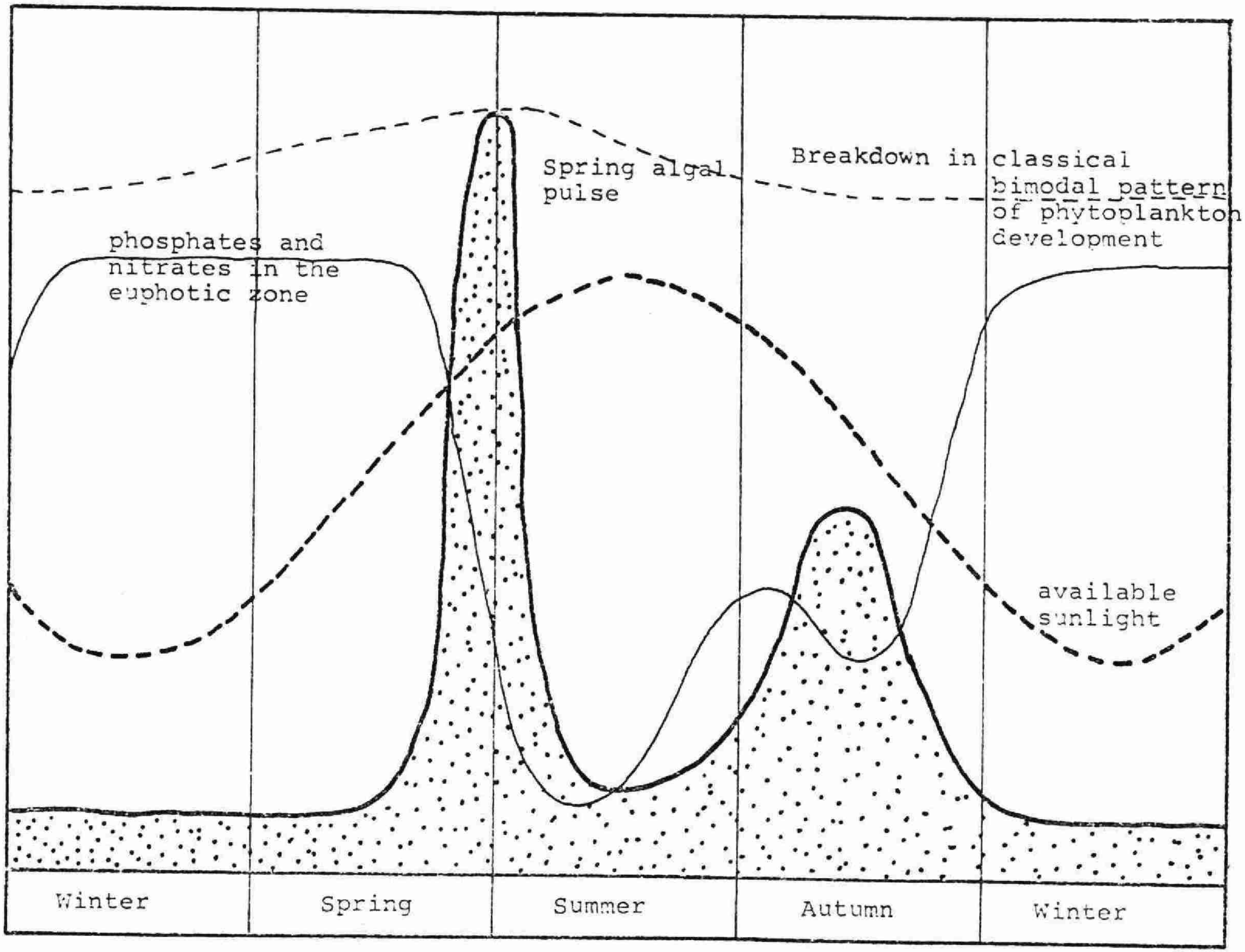

Figure 5. The spring algal increase and other seasonal features of primary production in Ontario lakes.
A breakdown in the pattern of phytoplankton development similar to that observed in Lake Erie is indicated.
Figure adapted from Russell-Hunter, 1970.

each summer season to aid in reducing the amount of algae reaching the filter beds. The addition of carbon to the flocculation chambers and anthrafilt to the filtration media assist further in prevention of problems caused by taste and odour type algae.

Taste and odour type algae have affected the water supply at Belleville in the Bay of Quinte. Aquatic weeds and algae, notably the taste and odour types, have caused problems in the Alexandria water supply on the Garry River in eastern Ontario, at Apsey Lake near Espanola, Clarke Lake at Bancroft, the Scugog River at Lindsay, Turner Lake near Cache Bay, Ruhl Lake, Hanover and Gull Lake at Kirkland Lake. In the latter instance I was never fully convinced that the taste and odour complaint was due to the alga Synura as claimed by Carl Schenk. It seems that while making a field investigation of the complaint, Carl discovered a dead body in the lake! Strangely, shortly after its removal, there were no further consumer complaints.

Most people in the waterworks field in Ontario are aware of the taste and odour problems experienced at Sudbury where Ramsay Lake was the main source of supply for the city. In May 1963, the diatom Navicula was present in record high numbers of 134,000 asu/ml. However, in the fall of 1965 a bloom of the filamentous blue-green Aphanizomenon created havoc for approximately two weeks as foul smelling water invaded the system. Threshold odour levels were greater than 200. Ultimately the lake was treated with copper sulphate to alleviate the problem.

Water quality assessments for potential sources of water have been made at Sundridge (Lake Bernard), Collingwood, Midland and Owen Sound on

Georgian Bay, Lake Huron Water Supply System at Grand Bend, Cobourg, Port Hope, Wellington, Ontario County and Kingston on Lake Ontario, Ameliasburg (Roblin Lake) and Barry's Bay (Lake Kaminiskeg). At Barry's Bay the Ministry was faced with providing water and sewage treatment at the same time. A small island was the only separation between the source of supply and the receiving waters for the sewage treatment plant.

In 1974 we undertook an up-dating of our information on algae in the Upper Great Lakes (Anon. 1975a). Long term data collected at two locations at Sault Ste. Marie and short term data from five locations at Thunder Bay were used to assess the water quality of Lake Superior as reflected by algal densities. The classical bimodal pattern of seasonal production was perfectly portrayed at Gros Cap, Lake Superior indicating the unenriched nature of that water body. A companion report (Anon. 1975b) was prepared for the Lake Huron and Georgian Bay portions of the Upper Great Lakes. Lake Huron locations examined in the study included Sarnia, Grand Bend, Goderich, Owen Sound and Collingwood. Again with minor variations the classical bimodal pattern of phytoplankton development occurred at all locations with notable absence of the bloom forming blue-green algae which typically characterize nutrient enriched waters.

Table 2 summarizes the mean quantities of algae measured as a.s.u. per ml at the various sites on the Upper Great Lakes. While the duration of the study period varies greatly with each location, the quantities are indicative of the trophic status at each location.

A third I.J.C. report (Anon. 1976) on the Lake Ontario and St. Lawrence River portion of the Lower Great Lakes was completed in July of 1975. This report summarized the available information at waterworks

Table 2. Summary of phytoplankton data collected from Upper Great Lakes sources. All results expressed in areal standard units per millilitre

Location	Source	Years	Numbers of samples	Mean Value
Sarnia	L. Huron	66-70	197	686
Grand Bend	L. Huron	64-74	308	528
Goderich	L. Huron	64-74	280	786
Collingwood	Georgian Bay	64&/68	142	280
Penetang	Penetang Bay	/69	36	2510
S.S. Marie	St. Mary's R.	65-74	189	109
S.S. Marie	L. Superior	65-73	163	116
Thunder Bay	Thunder Bay L. Superior	/73	20	178
Kingsville (Union)	L. Erie*	66-67	66	3635

*included for comparative purposes only

at South Peel and Cornwall and on intensive studies conducted by our Section in the Bay of Quinte. Analyses of long term data for Brockville was incomplete at the time of writing of this report. It has subsequently been completed and should provide a valuable addition to the information available on the Lower Great Lakes.

It is probably well known to most of you that many of the Ministry of the Environment's activities during the past ten or twelve years have been centred on the element "phosphorus". Phosphates in the Great Lakes, phosphates in detergents, phosphates in fertilizers, phosphates in sewage effluents. What are the phosphorus levels? What is the Ministry's policy on phosphorus removal from sewage? The Biology Branch input to the 1969 I.J.C. report (Anon. 1969) was only a small section in each of the three volumes but the recommendations for the need to implement phosphorus removal was clearly stated in these and other reports. Each of the many government agencies studying water quality in the Great Lakes during the 1960's stated time and again the need to implement phosphorus removal programmes. By 1970 the legislation was on the books in Ontario and the wheels were set in motion to actively do something about reducing phosphorus inputs and removing phosphorus from the aquatic environment. The limits set on phosphorus in detergent compounds and the tertiary treatment of sewage (ie. phosphorus removal) was given top priority with deadlines set for implementation of various aspects of the programme. Effective as of Jan. 1, 1973, detergents were to contain a maximum of 5% phosphate content. Sewage plants having effluents discharging to the lower Great Lakes were to have phosphorus removal equipment installed by 1973. The upper Great Lakes and then other inland plants were to have equipment for this purpose in operation by 1975. Between 1972 and 1975, controls on phosphorus

discharged to Lake Erie had been achieved through general improvements in sewage treatment facilities as well as through the implementation of the phosphorus removal programme.

In preparing our reports to the I.J.C., it became obvious that the plankton data submitted faithfully by the many waterworks operators since the inception of our "Provincial Algae Monitoring Programme" in 1965 was starting to bear fruit.

Since the Western Basin of Lake Erie has been pegged as a classic example of a highly enriched (ie "eutrophic") body of water, it has received much attention in studies by limnological groups. Its shallow morphometric features, surrounding dense, human population and consequently heavy municipal and industrial loadings, gave it top priority in the phosphorus removal programme. Naturally, the data collected at the Union Water Treatment Plant would be most valuable in showing the effects of phosphorus removal. With over ten years of regular weekly plankton analyses available from the Union Water Treatment Plant, we were able to prepare a comprehensive picture of what was happening to the phytoplankton at this location in the Western Basin of Lake Erie. A paper (Nicholls et al. 1976) presented to the 19th conference on Great Lakes Research entitled "A Reversal of Eutrophication of Lake Erie's Western Basin Suggested By Long Term Near-Shore Phytoplankton Monitoring" was co-authored by Ken Nicholls, Dave Standen, Gordon Hopkins and Elaine Carney.

I would like to elaborate on this paper somewhat as it is indicative of how valuable the long term data collected by the water works operator is and how it plays an important part in demonstrating the effects of a major Ministry policy such as phosphorus removal.

In view of the large programmes in both Canada and the U.S. to control phosphorus loadings to the Great Lakes, it is imperative that limnological studies of these lakes are continued so that assessments of any changes in the trophic status of the lakes may be made. The paper mentioned above presents phytoplankton data determined over a nine year period from Canadian near-shore waters collected at the Union Water Treatment Plant between 1967 and 1975 in the Western Basin of Lake Erie. Results from weekly collections in the Western Basin indicate that marked decreases in phytoplankton densities have occurred over the last four years and represent the first documentation of the recovery of Lake Erie following decreased P loadings.

There have only been two earlier attempts (Verduin 1964; Hohn 1969) to document long term changes (1938 to 1965) in the phytoplankton of the Western Basin of Lake Erie. Similarly only one study (Davis 1964) on phytoplankton samples collected at the Cleveland water supply from 1919-1963 has been made on the Central Basin of Lake Erie. Based on the quantitative changes in phytoplankton, both studies provided evidence for the rapid eutrophication of Lake Erie.

By the late 1960's and early 1970's attempts were made to halt this rapid eutrophication process. As mentioned above it was recognized that controls could be implemented within the Great Lakes Basin since phosphorus was known to be a limiting nutrient. It was estimated that the initial reduction of phosphates in detergents to less than 20% in 1970 effectively reduced the total discharge of detergent phosphate to Canadian waters by 25% to 30% (Gt. Lakes Water Qual. Bd. 1973). The state of Michigan, by a Public Act in 1971, limited the sale of detergents to those having phosphorus contents less than 8.7% (as P, by weight).

Prior to the implementation of these regulations, phosphorus of detergent origin likely contributed between 50% and 70% of the total P in sewage treatment plant effluent (Hetling and Carlich 1972; Prince & Bruce 1972) and about 40% of the total P loading to Lake Erie (Anon. 1970a).

Sweeney (1973) has related improved stream water quality to recent reductions in detergent phosphates in New York State and Michalski et al. (1975) demonstrated an improvement in Gravenhurst Bay, Lake Muskoka after implementation of phosphorus removal processes to sewage discharged to the Bay. However, no Great Lakes studies have reported on long term changes in phytoplankton or other enrichment indicators which might be expected to materialize as a result of decreased phosphorus inputs brought about by recent legislation.

The first phytoplankton analysis conducted by an operator at the Union plant was forwarded to our laboratory in November 1964. However, regular weekly submissions did not start flowing into our lab until March, 1966. For the purpose of this paper, the first full calendar year for analyses was 1967 so we have selected January 1967 as the start of this study and present nine years of data up to December 1975. All of the phytoplankton analyses were completed by Dave Standen at the Union Water Treatment Plant.

The water intake at Union is located 450 meters (1500') offshore at approximately 3 m (10') depth. The samples for phytoplankton analyses were collected from a continuously flowing raw water tap in the plant, concentrated using the sand filtration and Sedgwick Rafter techniques as outlined in "Algae Identification and Enumeration Course" manual, (Anon. 1970b). The phytoplankton biomass has been expressed as areal standard units (a.s.u.)

per ml (one a.s.u. is equivalent to the area of algal material subtended by 400 μm^2) since it allows a more realistic comparison of algal populations comprised of different sized cells than could be obtained from cell counts alone. There are other means of measurement which I will expand on later.

With the implementation of phosphorus removal programmes there has been a noticeable reduction in the total loadings to the Western Basin of Lake Erie. In particular, a significant reduction occurred between 1970 and 1971 when the daily average input from the Detroit River dropped from 71.2 metric tons to about 41.6 metric tons (Figure 6). There are only four years of comparison data available on total phosphorus concentration at the Union Water Treatment Plant but they generally agree with the loading data. The pre-1970 concentrations were considerably higher than the 1971-1972 concentrations and coincided with the decline in phosphorus loading during the same period. We began collecting P concentration data on companion samples early in 1976 at many of the waterworks where phytoplankton data is recorded, including the Union Plant. At the time of writing the data collected indicate a continued low concentration paralleling lowered algal densities.

However, demonstrating a decline in total phosphorus concentrations in Lake Erie's Western Basin alone does not provide sufficient evidence for a reversal of the eutrophication process. The effectiveness of the Phosphorus Control Programme can only be determined by recorded declines in the phytoplankton biomass.

Phytoplankton densities recorded during the nine year period showed that the lowest levels occurred during the summer of 1975. However, total biomass has declined over all seasons of the annual period in recent

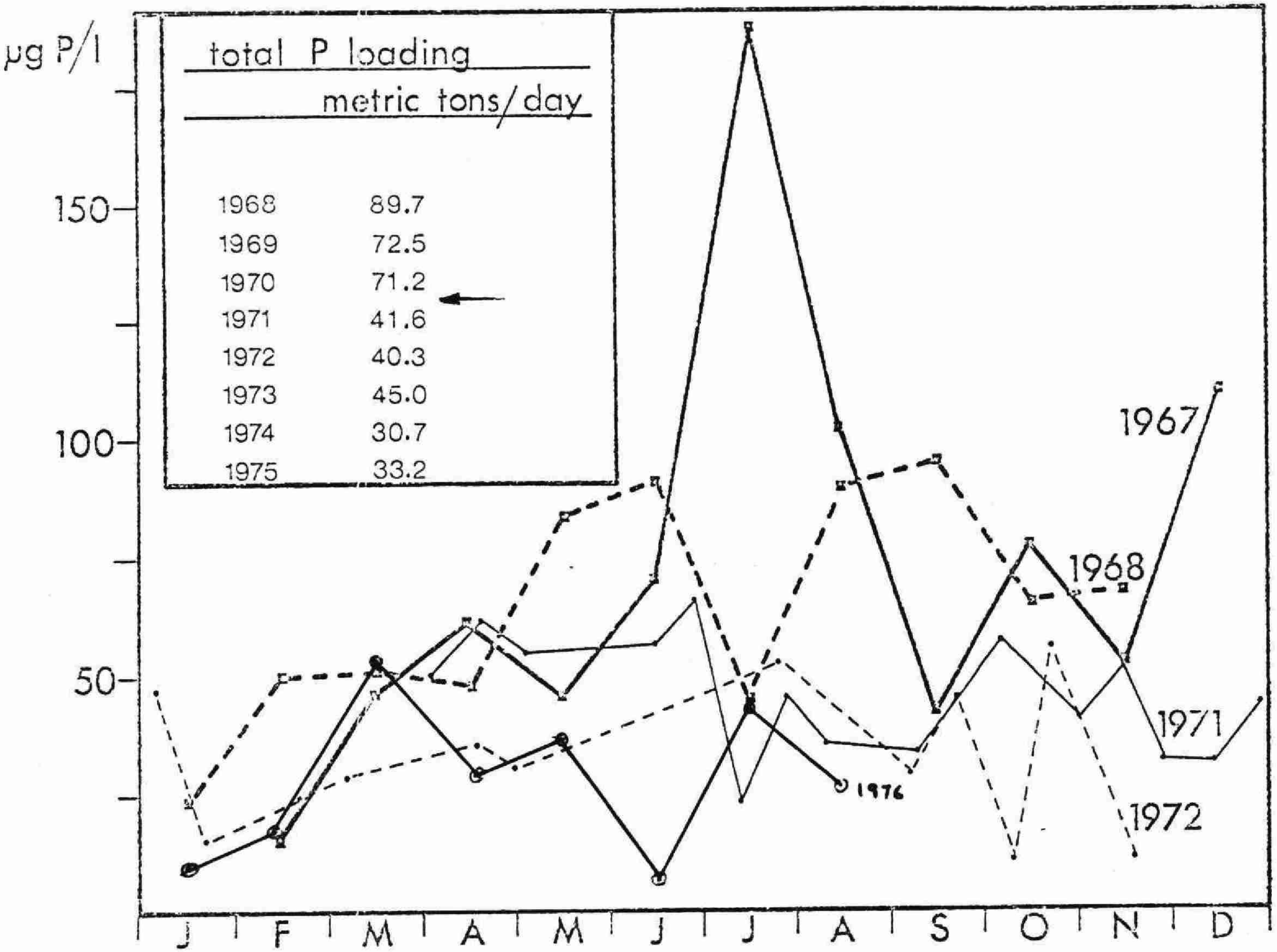

Figure 6. Concentrations of total phosphorus in "raw" water collected at the Union Water Treatment Plant during 1967, 1968, 1971, 1972 and 1976. Also presented are total phosphorus loading data from the Detroit R. provided by Mr. T. Newell, Mich. Dept. Nat. Resources. Fig. adapted from "Nicholls et al, 1976".

years (Figure 7). This is a very important graph and I would like to spend the next half hour or so explaining the significance of each of these lines. Moving on now to Figure 8 it may be seen that there has been a steady decline in the average algal biomass since 1971 so that by the end of 1975 the mean biomass of 2900 a.s.u./ml represents a reduction of 42% from a mean biomass of 5010 a.s.u./ml calculated for the pre-phosphorus control years of 1967 to 1970. I have included the mean value of 2955 a.s.u./ml and 2749 a.s.u./ml for the first eight months of 1975 and 1976 respectively in Figure 8.

As mentioned previously, the classical bimodal pattern of algal development did not occur at Union. While March-April biomass densities and late summer-fall biomass densities were higher than the winter and mid-summer lows the fluctuations were less accentuated. Davis (1964) provided evidence for the rapid eutrophication of Lake Erie's Central Basin based in part on a change from bimodal distributions of phytoplankton to more uniform seasonal distributions including mid-summer maxima.

Most of the decline in algal densities at Union can be attributed to lower densities of the diatom group (Bacillariophyceae) which have dominated the phytoplankton during the period of time under study. The other algal classes were of lesser importance although certain members of the Chlorophyceae, Cyanophyceae, Dinophyceae and Cryptophyceae did achieve importance for short periods of time. The order of dominance of each group remained unchanged over the period of study. In the paper presented at the 19th Conference on Great Lakes Research we elaborated on the composition of the diatom taxa and the relative importance of each. It will suffice to say here that the dominant diatom in the Union plant samples over the

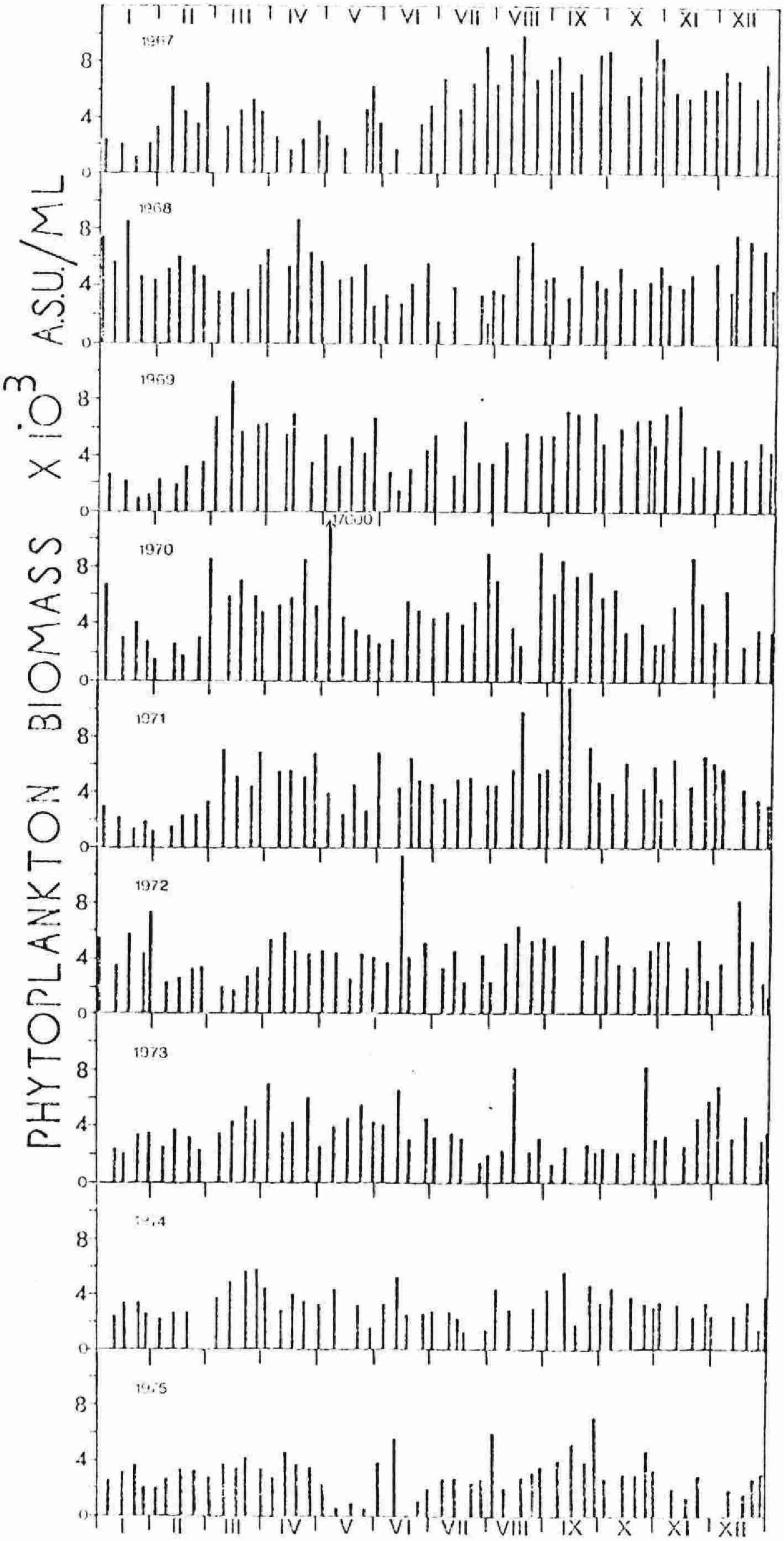

Figure 7. Seasonal distribution of total phytoplankton biomass (as areal standard units/ml) in samples of "raw" water collected from the Union Water Treatment Plant at Kingsville between 1967 and 1975. "From Nicholls et al 1976".

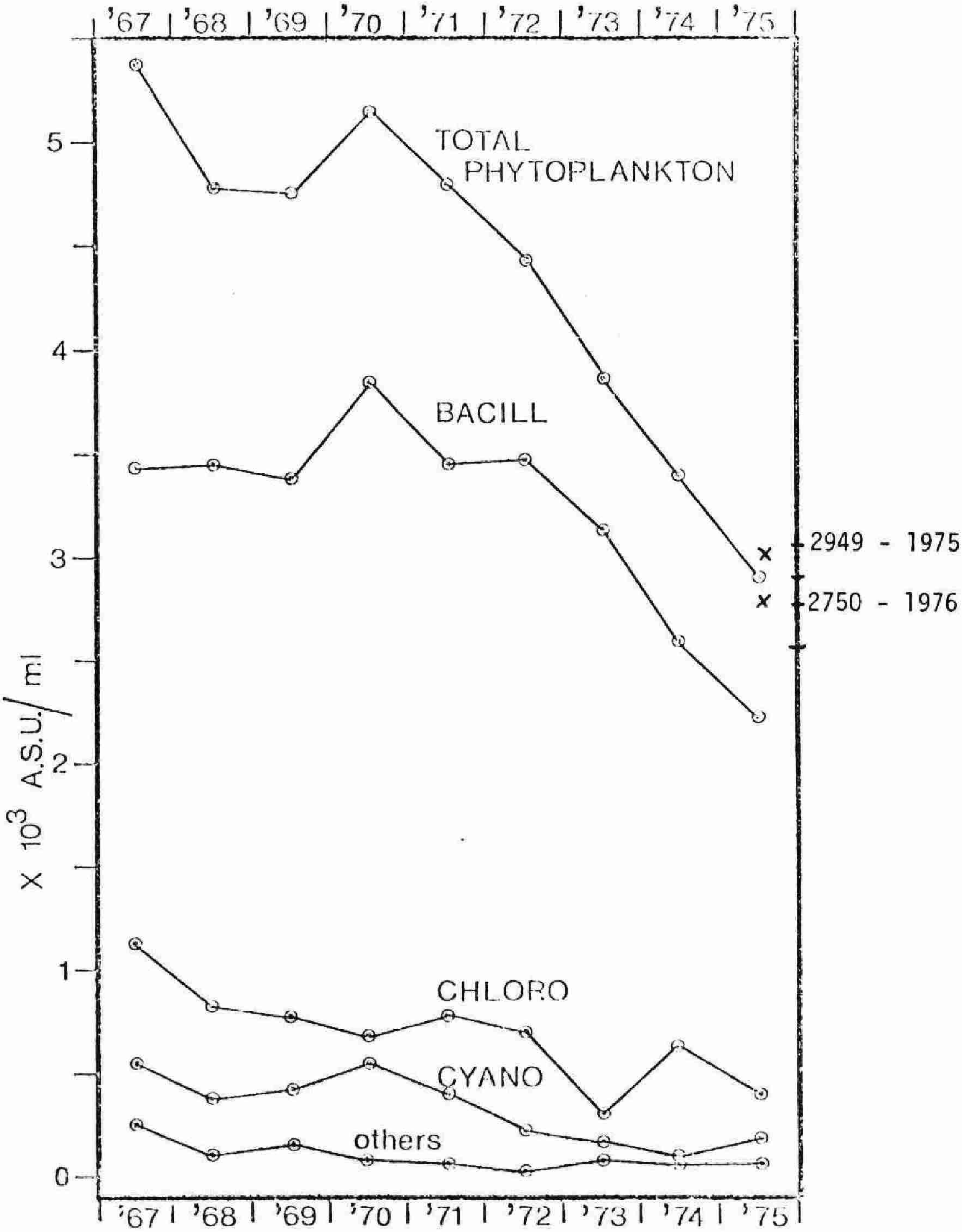

Figure 8. Average biomass (as areal standard units/ml) of total phytoplankton and the dominant Classes between 1967 and 1975 at the Union Water Plant. Keyed as follows: BACILL - Bacillariophyceae, CHLORO - Chlorophyceae, CYANO - Cyanophyceae. Data for first 8 months 1975 and 1976 included. Adapted from "Nicholls et al 1976".

nine year study period has been Fragilaria. The development of F. capucina as a dominant form has apparently characterized the eutrophication process of western Lake Erie, since Hohn (1969) found only small quantities of it in the late 1930's and has documented its steady increase until 1965 when it became a full dominant. In the Union data Fragilaria spp. has represented a fairly constant 40% of the diatom flora despite an overall decrease in phytoplankton biomass since 1970.

Hohn (1969) indicated that Asterionella formosa maintained constant densities between 1938 and 1965 while total biomass increased. Our data indicate that Asterionella has remained constant at about 5% of the total diatom biomass throughout the entire study period. Hohn's data suggests that the decline in Asterionella then is not related entirely to decreased nutrient loadings.

The second most important group was the Chlorophyceae represented most abundantly by Scenedesmus and Pediastrum spp. Prior to 1970 the blue-greens (Cyanophyceae) represented about 10% of the total biomass. Since 1970 they have declined to a scant 3% of the total biomass. This reduction in the Cyanophyceae parallels similar responses observed in Gravenhurst Bay (Michalski et al, 1975) where total phytoplankton biomass was reduced by 50% but blue-greens dropped by 85%. Gravenhurst Bay, Lake Muskoka has experienced increased representation by the Chrysophyceae following reduced phosphorus loadings. It will be interesting to see if a similar occurrence develops in Lake Erie's Western Basin if phosphorus inputs and phosphorus concentrations continue to decline.

Periodically phytoplankton data are selected from our files to complement other information being assembled for papers or reports.

W. Hutchison formerly of the Water Technology Section of the Research and Development Branch has incorpo ted phytoplankton data collected at Lampton, Grand Bend and Goderich into operational papers which have been published in the Journal A.W.W.A. (Hutchison and Foley 1974; Hutchison 1975, 1976).

Current Programme

Early in 1975 the Water Quality Surveillance Committee of the I.J.C. requested that we conduct a sampling programme that would provide complementary chemical data to the existing phytoplankton information which was currently available at water supply intakes on the Great Lakes. Again, I cannot overemphasize the importance of samples collected at regular weekly intervals on a year round basis by the waterworks personnel. I know of no other agency in Canada or the U.S. that has acquired such regular long term information and it is a credit to you, the operations staff, for providing us with this good record.

While I have rambled on about various uses made of information on samples originating at the waterworks intakes, I expect you will be interested in the current programme which is generating weekly data on eleven parameters at eleven waterworks intakes. I am not a chemist so I am not totally aware of the importance of the various chemical parameters requested in this study. I can show you the parameters (Table 3) and provide you with an indication of the ranges (Anon. 1975c) which might be expected to occur at these locations in the great lakes.

I would like to comment briefly on each of the parameters included in Table 3. Total phosphorus occurs naturally in surface waters and is an essential element for all life forms. Artificial inputs of phosphorus

Table 3. Summary of Parameters, their analytical ranges and detection limits, and the maximum and minimum levels to date in this study*

Parameter	Range on Undiluted Sample**	Detection Limit**	Max-Min Levels on Samples*	
*this study			Max.	Min.
Total Phosphorus as P	.004-0.2 mg/l	.004 mg/l	.170 (.308)	.004
Dissolved Reactive* Phosphorus as P *Filtered	.002-0.2 mg/l	.002 mg/l	.055	.001
Nitrogen - Free Ammonia	.01-1.0 mg/l	.01 mg/l	.186 (.315)	<.002
Nitrogen - Total Kjeldahl	0.1-2.0 mg/l	0.1 mg/l	.980 (1.9)	.065
Nitrogen - Nitrite (NO_2)	.002-0.2 mg/l	.002 mg/l	.039 (.244)	<.001
Nitrogen - Nitrate (NO_3)	.02-2.0 mg/l	.02 mg/l	2.60	<.01
Chloride	4-400 mg/l .1-10 mg/l	4 mg/l 0.1 mg/l	49	5.0
Reactive Silicon	0.1-5 mg/l	0.1 mg/l	5.8	<.05
Chlorophyll a in µgm/l	1-8 mg/m^3	1 mg/m^3	16	<.1

*Great Lake Surveillance Study, 1976

**In "Outlines of Analytical Methods" Anon. 1975.

play a significant role in promoting over-abundance of algae and aquatic plants which may impair water quality. Phosphorus results are used in assessing a waters' potential for biological productivity as well as the efficiency of nutrient removal at waste treatment plants.

Values in excess of 25 µg/l total phosphorus (Anon. 1972) may be responsible for excessive algal growths. Although there is no firm criterion for phosphorus, Sawyer (1947) suggested that 300 µg/l of inorganic nitrogen (N) and 10 µg/l of soluble phosphorus (P) at the start of the growing season could produce nuisance algal blooms. If you look at the graph for the Union data again (Figure 6) you can see where 25 µg/l lies. Take the values for data from your own plant and plot them against this graph and you will obtain some feel for the fluctuation in total P concentrations throughout the year.

Nitrogen determinations are broken down into four components to separate the organic nitrogen from the inorganic nitrogen. Briefly the nitrogen cycle is a decomposition process from total organic compounds to free ammonia, to nitrite, to nitrate, all inorganic forms. Through photosynthetic action free ammonia and nitrates may be utilized to regenerate more organic matter. In assessing nutrient parameters in relation to algal growths, a good rule of thumb is to compare the total Kjeldahl nitrogen to the total P. If the algae are utilizing all the nutrients, these two parameters will be in the ratio of 10 - 20:1. If the ratio does not fall within this range then you can look at the free ammonia and nitrate parameters to see if there are appreciable amounts of these forms present. The concentrations of phosphorus and nitrogen are usually minimal in natural run-off. In lakes receiving excessive inputs of sewage and/or agricultural

run-off the ratio of N:P will be lowered as will be the ammonia and nitrate components during the summer growth period as a result of algal assimilation of all the available inorganic nitrogen. Relative to nitrogen, phosphorus in sewage enriched lakes is often supplied in excess of the requirements for algae.

The element silicon is second only to oxygen in abundance and is present as silica or silicates in sand. They are present in natural waters as silicates and are essential to the growth of diatom type algae. A reduction in algal densities, if diatoms are dominant, may be caused by silica depletion.

Chlorophyll a and Chlorophyll b are measured in µg/l quantities. Chlorophyll a and b are found in the green algae whereas the blue-greens contain only chlorophyll a. The chrysophytes including the diatoms and the chrysomonads contain Chlorophyll a and c. Chlorophyll c is not measured in our laboratory. Chlorophyll b is often very small in relation to chlorophyll a. High chlorophyll values cause greater analytical variability and interpretation of results showing values greater than 20 µg/l should be examined with caution (Anon. 1975c). Chlorophyll values may be used as an indicator of eutrophy. Chlorophyll a concentrations less than 2 µg/l will reflect low algal densities and unenriched conditions. Concentrations greater than 4 µg/l will reflect moderately high algal densities and enriched conditions. A single high reading may only reflect a short-lived algal pulse. It should be emphasized that there are many factors which determine the chlorophyll content of algal cells and that chlorophyll measurements provide a simple but only approximate indication of algal biomass.

Chloride as Cl, (measured in mg/l) is a fairly common component of natural waters but does not generally pose a direct health hazard. To prevent detection of salty tastes occurring, a limit of 250 mg/l has been set as the water quality objective for water supplies (Anon. 1975c). Chloride salts are very soluble and do not readily come out of solution. For this reason chloride concentrations build up as they pass through the Great Lakes. Current Lake Ontario levels are approximately 26-28 mg/l (Anon. 1969). Chloride values prior to 1910 were <10 mg/l (Beeton, 1965). Chloride is a good indicator of localized urban and industrial pollution inputs.

How do you handle this massive accumulation of data? Every week, each participant is receiving data for eleven parameters which are probably documented on three or four separate analyses report forms. The best means is to obtain a master ledger where all the data for a single year may be recorded on a single page. At the end of the year the maximum, minimum and mean values may then be recorded. Successive years may then be recorded in the same fashion. After three or four years the annual mean values may then be plotted to indicate the long term trends. Going back to the Union data which I presented earlier, phytoplankton data for 9 years were presented as individual histograms in Figure 6. In Figure 7 this information was further reduced to a single line graph.

By keeping a continuous ledger on the data as they are accumulated, you may observe typographical errors or reporting errors due to misplaced decimals, transcription error or in fact real outlyer results due to some explainable reason. For example, in the current data total phosphorus for May 10 was reported as .40 mg/l. Values for the week prior and the week

following were .081 and .034 mg/l respectively. Upon checking with the London lab it was found that a decimal error has occurred and the May 10th reading should be .04 mg/l.

Similarly, a reading for Chloride at South Peel on June 10 was reported as 2.85 mg/l whereas the previous week it was 31.5 mg/l and the week following it was 28.5 mg/l. By the same token I discovered that no phytoplankton data had been received from Amherstburg since February '76. It had been short circuited at the London Regional Office where both copies of the weekly report were being filed away.

In order to see the effects of the different parameters on one another and on the phytoplankton, various plots can be made of one parameter vs. another. Figure 9 (Nicholls 1976) shows the relationship between chlorophyll a and total P and between phytoplankton cell volume and total P. For this latter graph a good statistical correlation was achieved. Chlorophyll a data vs. secchi disc readings (Figure 10) have been used successfully to measure the trophic status of many recreational lakes in Ontario (Anon. 1974). Figure 11 (Nicholls 1976) is another example using a specific algal group in relation to total P. Lower concentrations of phosphorus resulting from reduced P loadings from sewage treatment facilities correlated well with increased Chrysophyceae as a percent of total biomass.

I would like to direct some attention now to the "Phytoplankton Monitoring Programme" and problems that have arisen as a result of our selection of techniques. If any of you have ever attended a workshop on methodology which involves several different agencies you are probably well aware of the fact that methods for completing similar tasks vary with each agency. This is especially true with quantitative investigations involving phytoplankton. There are as many methods as there are agencies and then

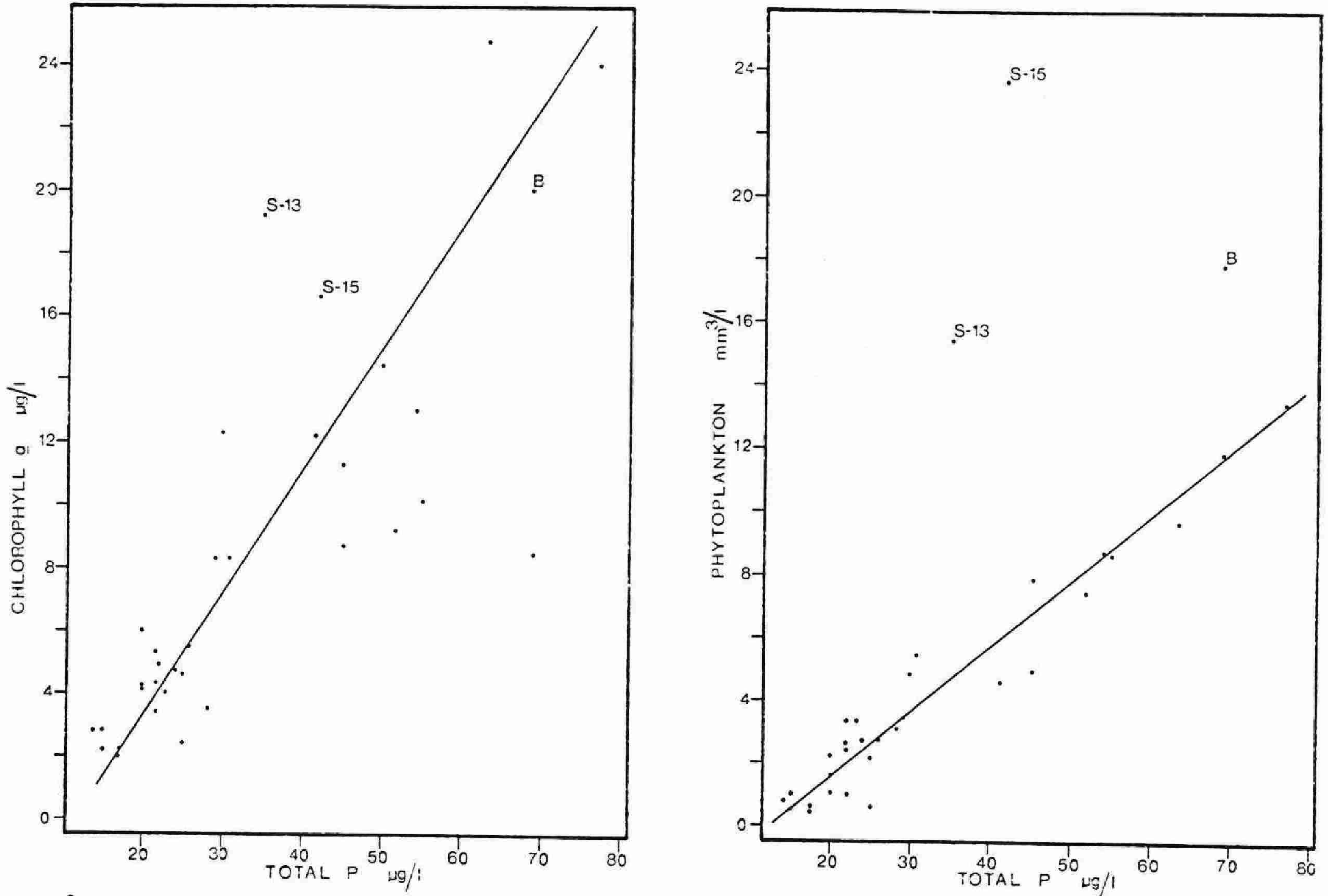

Figure 9. Relationships between average total phosphorus concentration and chlorophyll a and between total phosphorus concentration and total phytoplankton cell volume at the 27 Kawartha-Trent phytoplankton sampling locations and at 7 "downstream" locations in the Bay of Quinte between Trenton and Lake Ontario. In delineating the regression of average total P onto average phytoplankton cell volume, the noticeable outliers (S-13, S-15 and Station B - Belleville, Bay of Quinte) were ignored. Note that these three data points are within the much broader range of scatter of the total P - chlorophyll a relationship. See also the caption for Figure 5. "From Nicholls 1976"

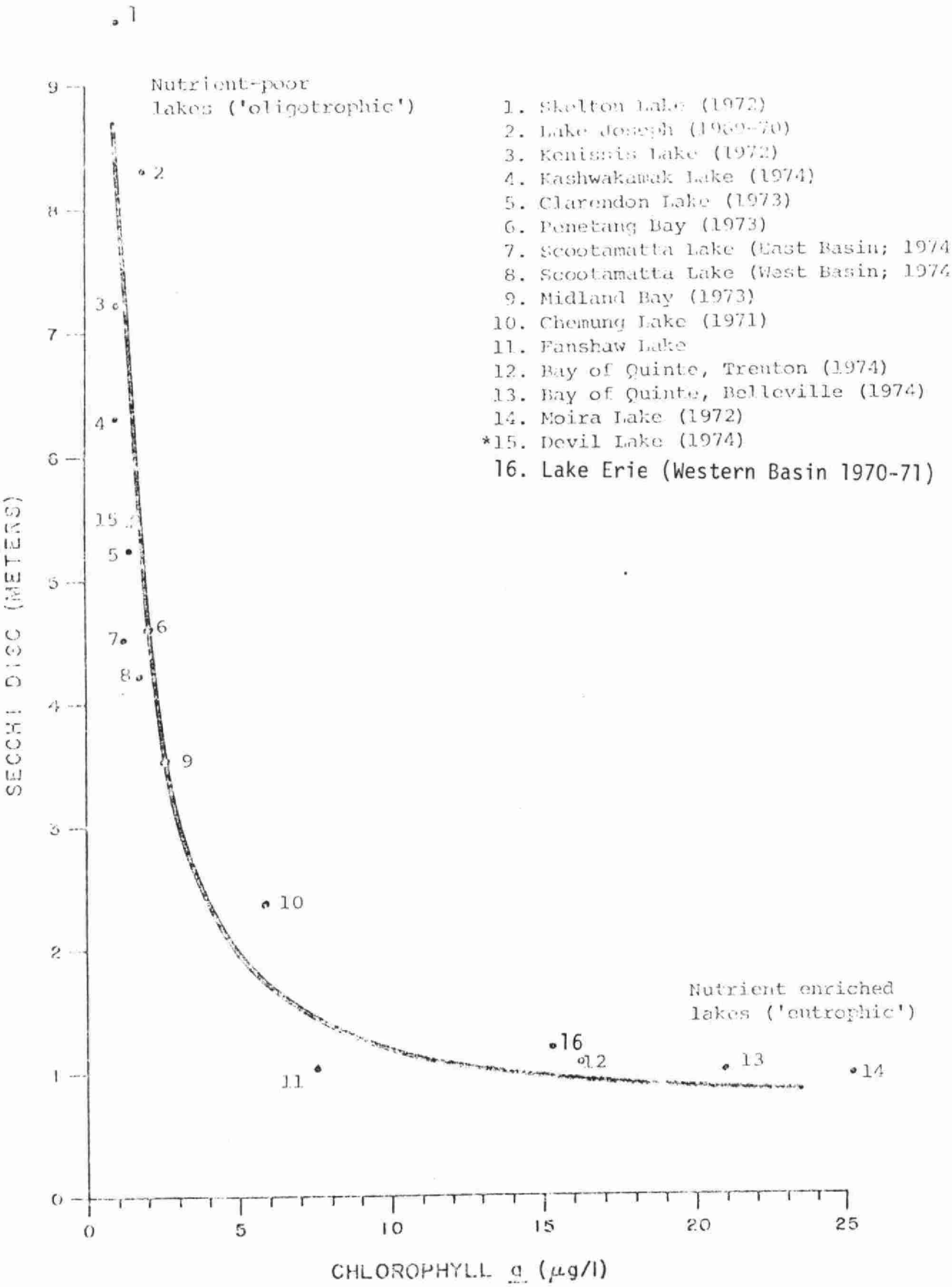

Figure 10. Relationship between chlorophyll a and Secchi disc developed from data on over 100 Ontario Lakes and showing the status of enrichment of Devil Lake relative to several other lakes in the province. From "Anon. 1974".

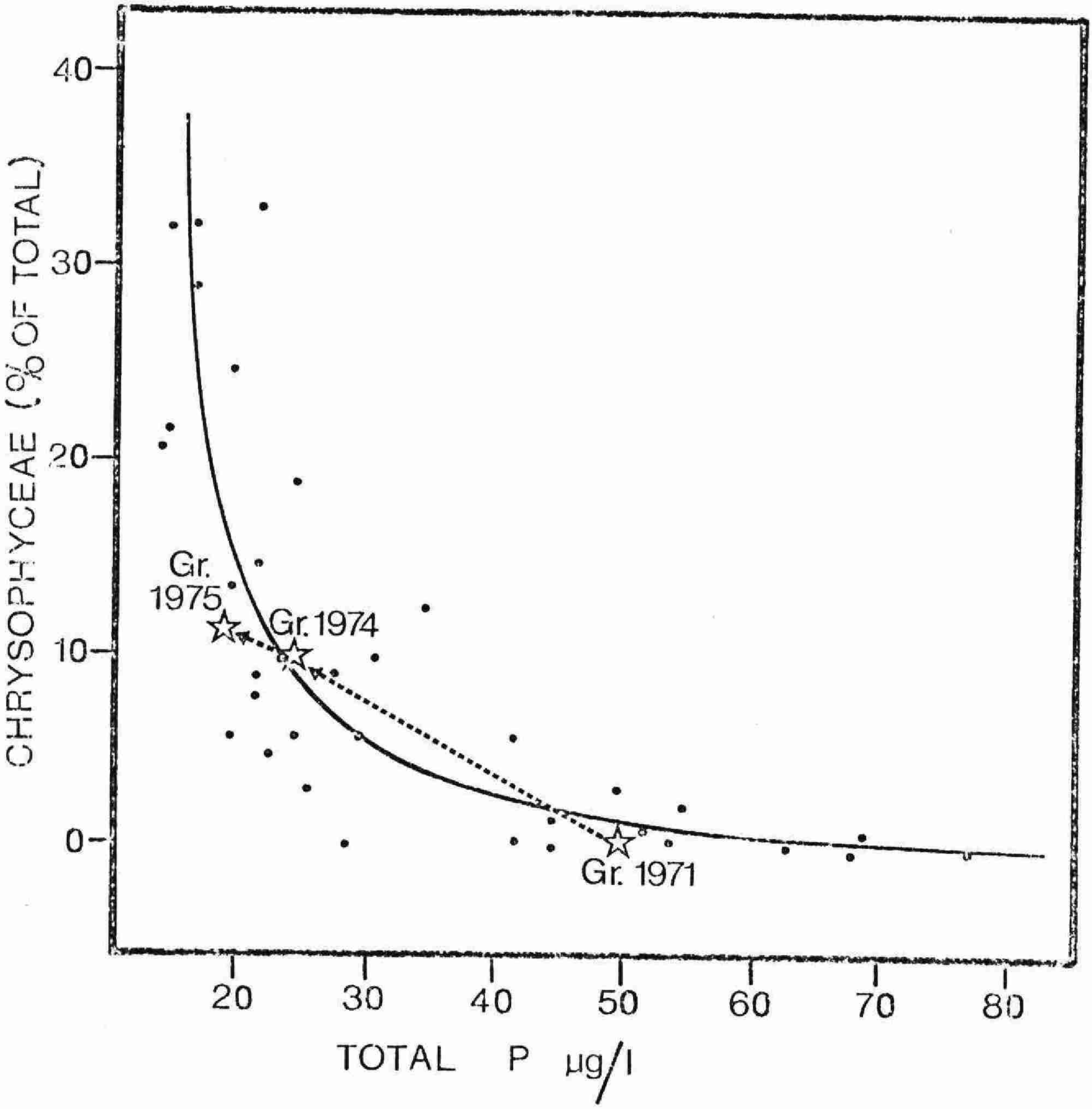

Figure11. Relationship between average total phosphorus concentration and the percentage contribution by Chrysophyceae to the total phytoplankton biomass at the 27 Kawartha-Trent phytoplankton sampling locations and at 7 "downstream" locations in the Bay of Quinte between Trenton and Lake Ontario. Also indicated are 1971 data from Gravenhurst Bay of Lake Muskoka prior to reductions in phosphorus loading from municipal sewage treatment facilities and 1974-75 data illustrating the change resulting from implementation of a phosphorus removal programme (tertiary treatment) during 1971. "From Nicholls 1976".

some. Despite our own efforts to maintain a single standard method, we are in fact currently reporting results using two methods. The Areal Standard Unit Method of areal measurement measures biomass as asu/ml and the phytoplankton cell volume measurement expresses algal densities as cubic millimeters of algal biomass per litre (mm^3/l).

Standard Methods (A.P.H.A. 1965) indicates that the Sedgwick Rafter sand filtration technique is a means for concentrating algae. We used this technique from 1963 to 1968 at which time we gradually introduced the Lugol's iodine sedimentation technique for concentrating and preserving algae. Originally all our samples were preserved with a 3% Formalin solution but Lugol's iodine is now used almost exclusively in our programme. Formaldehyde as a preservative caused severe cell damage to some algal species whereas Lugol's solution accentuated some algal cell characteristics aiding in identification. The sand filtration technique resulted in a loss of 5-15 percent of the algae which was either trapped in the silk bolting cloth or the sand or was siphoned on through. Settling the algae out in graduated cylinders using Lugol's solution preserved the algae with less cell damage and the supernatant was more readily decanted after settling with less loss of cells through the siphoning action.

In the Rexdale laboratory we are using Inverted microscopes which allow us to examine the concentrated samples quantitatively at 600X magnification. This has greatly facilitated the identification of many of the smaller nannoplankton particularly the small chrysophytes which are hardly discernable as algae at 200X magnification. We have found that the Chrysophyceae as a class are more abundant in waters of low nutrient concentrations. Taxonomically we are separating the algae into their proper

scientific Classes to facilitate manipulation of the data when preparing reports for scientific journals etc.

You may have come across reports where measurements of algal biomass has been reported in units other than asu/ml. Biomass can be estimated chemically by means of chlorophyll measurements, by wet weight of algae removed on filters, microscopically by counting algal cells, areally by measuring algal cells and volumetrically be measuring algal cells. The latter two methods are the best means of quantifying the biomass present. Making volumetric measurements of algal cells allows greater flexibility in comparing the data quantitatively with other chemical parameters which may have been measured simultaneously. Volumetric measurements are usually reported as cubic millimeters of algal biomass per litre of water (mm^3/l). Assuming algal density as one (1) allows the ready conversion to mg/l units which is then directly comparable to measured nutrient parameters.

As I mentioned previously, the Ontario Ministry of the Environment is one of the few agencies in the world which has built up a year round record of phytoplankton data from a number of single point sources. The fact that the source does not change from year to year eliminates some of the sampling error which occurs when trying to relocate sampling stations reached only by boat. While techniques employed at the waterworks may be lacking to some extent in taxonomic expertise, we feel that the objectives of the phytoplankton monitoring programme are more than adequately met through the efforts of the waterworks personnel who are counting algae for this Ministry.

Figure 1: Participants in the first "Algae Identification and Enumeration Course" sponsored by the Ontario Water Resources Commission, April, 1963.

Front row - Ken Allen, Kingston; Glen Owen, O.W.R.C; Don Burden, Sudbury; Jim Scriven, Belleville; Anne-Marie Kuppe, Hamilton; Carl Schenk, O.W.R.C.

Back row - John Neil, O.W.R.C., Gordon Hopkins, O.W.R.C; Earl Myers, Cornwall; Alf Shingler, Cedar Springs; Len Pridie, Whitby; Vance Langford, Chatham; Jim Harrison, Peterborough; Ted Grozelle, Cobourg

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